CLAIMS

1. A bi-directional cross-connect apparatus comprising:

a first port;

a second port;

a third port;

a fourth port; and

routing means for directing signals comprising wavelength channels from a first subset of optical frequencies between the first port and the third port, and between the second port and the fourth port, and for directing signals comprising wavelength channels from a second set of optical frequencies, independent of the first subset of optical frequencies, between the first port and the fourth port, and between the second port and the third port.

2. The apparatus according to claim 1, further comprising an optical device coupled between the third port and the fourth port, wherein the optical device is selected from the group consisting of a channel equalizer, an optical amplifier, an erbium doped fiber amplifier, and an Add/Drop multiplexer.

3. The apparatus according to claim 1, wherein the routing means includes an optical channel interleaver of the type selected from the group consisting of a birefringent crystal interleaver, a multi-cavity etalon interleaver, and a Michelson Gires Tournois intrerleaver.

4. The apparatus according to claim 1, wherein the routing means comprises a birefringent crystal interleaver including a first birefringent element of length L, and a second birefringent element of length 2L, wherein crystal axes of the first and second birefringent elements are oriented differently; whereby the polarization of the wavelength channels in the first subset of optical frequencies is rotated by substantially 90°, while the polarization of the wavelength channels in the second subset of optical frequencies is substantially unchanged.

5. The apparatus according to claim 1, wherein the routing means comprises a birefringent crystal interleaver including a first birefringent element of length L, a second

birefringent element of length 2L, and polarization rotators between the first and second birefringent elements; whereby the polarization of the wavelength channels in the first subset of optical frequencies is rotated by substantially 90°, while the polarization of the wavelength channels in the second subset of optical frequencies is substantially unchanged.

6. The apparatus according to claim 1, wherein the routing means comprises a birefringent crystal interleaver including:

a first birefringent element of length L;

reflecting means for directing signals through the first birefringent element for a plurality of passes; and

polarization rotating means for rotating the polarization of the signals after at least one of the passes;

whereby the polarization of the wavelength channels in the first subset of optical frequencies is rotated by substantially 90°, while the polarization of the wavelength channels in the second subset of optical frequencies is substantially unchanged.

7. The apparatus according to claim 4, wherein the routing means further comprises:

first polarization beam splitter means for dividing signals launched via the first port into orthogonally polarized sub-beams, and for combining orthogonally polarized sub-beams launched via the third or fourth ports for output via the first port;

first polarization rotating means for ensuring both sub-beams exiting the first polarization beam splitter means have a first polarization, and for ensuring both sub-beams entering the first polarization beam splitter means have orthogonal polarizations;

second polarization beam splitter means for dividing signals launched via the second port into orthogonally polarized sub-beams, and for combining orthogonally polarized sub-beams launched via the third or fourth ports for output via the second port;

second polarization rotating means for ensuring both sub-beams exiting the second polarization beam splitter means have a second polarization, and for ensuring both sub-beams entering the second polarization beam splitter means have orthogonal polarizations;

third polarization beam splitter means for dividing signals launched via the third port into orthogonally polarized sub-beams, and for combining orthogonally polarized sub-beams launched via the first or second ports for output via the third port;

third polarization rotating means for ensuring both sub-beams exiting the third polarization beam splitter means have a first polarization, and for ensuring both sub-beams entering the third polarization beam splitter means have orthogonal polarizations;

fourth polarization beam splitter means for dividing signals launched via the fourth port into orthogonally polarized sub-beams, and for combining orthogonally polarized sub-beams launched via the first or second ports for output via the fourth port;

fourth polarization rotating means for ensuring both sub-beams exiting the fourth polarization beam splitter means have a second polarization, and for ensuring both sub-beams entering the fourth polarization beam splitter means have orthogonal polarizations;

first polarization dependent beam directing means for directing sub-beams between the first port and the birefringent crystal interleaver, and for directing sub-beams between the second port and the birefringent crystal interleaver; and

second polarization dependent beam directing means for directing sub-beams between the birefringent crystal interleaver and the third port, and for directing sub-beams between the birefringent crystal interleaver and the fourth port.

8. The apparatus according to claim 5, wherein the routing means further comprises:

first polarization beam splitter means for dividing signals launched via the first port into orthogonally polarized sub-beams, and for combining orthogonally polarized sub-beams launched via the third or fourth ports for output via the first port;

first polarization rotating means for ensuring both sub-beams exiting the first polarization beam splitter means have a first polarization, and for ensuring both sub-beams entering the first polarization beam splitter means have orthogonal polarizations;

second polarization beam splitter means for dividing signals launched via the second port into orthogonally polarized sub-beams, and for combining orthogonally polarized sub-beams launched via the third or fourth ports for output via the second port;

second polarization rotating means for ensuring both sub-beams exiting the second polarization beam splitter means have a second polarization, and for ensuring both sub-beams entering the second polarization beam splitter means have orthogonal polarizations;

third polarization beam splitter means for dividing signals launched via the third port into orthogonally polarized sub-beams, and for combining orthogonally polarized sub-beams launched via the first or second ports for output via the third port;

third polarization rotating means for ensuring both sub-beams exiting the third polarization beam splitter means have a first polarization, and for ensuring both sub-beams entering the third polarization beam splitter means have orthogonal polarizations;

fourth polarization beam splitter means for dividing signals launched via the fourth port into orthogonally polarized sub-beams, and for combining orthogonally polarized sub-beams launched via the first or second ports for output via the fourth port;

fourth polarization rotating means for ensuring both sub-beams exiting the fourth polarization beam splitter means have a second polarization, and for ensuring both sub-beams entering the fourth polarization beam splitter means have orthogonal polarizations;

first polarization dependent beam directing means for directing sub-beams between the first port and the birefringent crystal interleaver, and for directing sub-beams between the second port and the birefringent crystal interleaver; and

second polarization dependent beam directing means for directing sub-beams between the birefringent crystal interleaver and the third port, and for directing sub-beams between the birefringent crystal interleaver and the fourth port.

9. The apparatus according to claim 6, wherein the routing means further comprises:

first polarization beam splitter means for dividing signals launched via the first port into orthogonally polarized sub-beams, and for combining orthogonally polarized sub-beams launched via the third or fourth ports for output via the first port;

first polarization rotating means for ensuring both sub-beams exiting the first polarization beam splitter means have a first polarization, and for ensuring both sub-beams entering the first polarization beam splitter means have orthogonal polarizations;

second polarization beam splitter means for dividing signals launched via the second port into orthogonally polarized sub-beams, and for combining orthogonally polarized sub-beams launched via the third or fourth ports for output via the second port;

second polarization rotating means for ensuring both sub-beams exiting the second polarization beam splitter means have a second polarization, and for ensuring both sub-beams entering the second polarization beam splitter means have orthogonal polarizations;

third polarization beam splitter means for dividing signals launched via the third port into orthogonally polarized sub-beams, and for combining orthogonally polarized sub-beams launched via the first or second ports for output via the third port;

third polarization rotating means for ensuring both sub-beams exiting the third polarization beam splitter means have a first polarization, and for ensuring both sub-beams entering the third polarization beam splitter means have orthogonal polarizations;

fourth polarization beam splitter means for dividing signals launched via the fourth port into orthogonally polarized sub-beams, and for combining orthogonally polarized sub-beams launched via the first or second ports for output via the fourth port;

fourth polarization rotating means for ensuring both sub-beams exiting the fourth polarization beam splitter means have a second polarization, and for ensuring both sub-beams entering the fourth polarization beam splitter means have orthogonal polarizations;

first polarization dependent beam directing means for directing sub-beams between the first port and the birefringent crystal interleaver, and for directing sub-beams between the second port and the birefringent crystal interleaver; and

second polarization dependent beam directing means for directing sub-beams between the birefringent crystal interleaver and the third port, and for directing sub-beams between the birefringent crystal interleaver and the fourth port.

10. The apparatus according to claim 1, further comprising:

first bi-directional isolator means between the first port and the routing means for passing first signals comprising wavelength channels from a first subset of optical frequencies, while preventing wavelength channels from a second subset of optical frequencies from passing therebetween; and

second bi-directional isolator means between the second port and the routing means for passing second signals comprising wavelength channels from the second subset of optical frequencies, while preventing wavelength channels from the first subset of optical frequencies from passing therebetween;

whereby the first and second signals are routed from the first and second ports, respectively, to the third port, and routed from the fourth port to the second and first ports, respectively.

11. The apparatus according to claim 10, wherein the first and second bi-directional isolator means comprise:

wavelength selective polarization rotating means for rotating the polarization of the first subset of optical frequencies, while have no substantial cumulative effect on the polarization of the second subset of optical frequencies;

non-reciprocal polarization rotating means for rotating the polarization of the signals passing from the third or fourth ports to the first or second ports, while having substantially no cumulative effect on the polarization of signals passing in the opposite direction.

12. The apparatus according to claim 5, further comprising:

first bi-directional isolator means between the first port and the routing means for passing first signals comprising wavelength channels from a first subset of optical frequencies, while preventing wavelength channels from a second subset of optical frequencies from passing therebetween; and

second bi-directional isolator means between the second port and the routing means for passing second signals comprising wavelength channels from the second subset of optical frequencies, while preventing wavelength channels from the first subset of optical frequencies from passing therebetween;

whereby the first and second signals are routed from the first and second ports, respectively, to the third port, and routed from the fourth port to the second and first ports, respectively.

13. The apparatus according to claim 12, wherein the first and second bi-directional isolator means comprise:

wavelength selective polarization rotating means for rotating the polarization of the first subset of optical frequencies, while have no substantial cumulative effect on the polarization of the second subset of optical frequencies;

non-reciprocal polarization rotating means for rotating the polarization of the signals passing from the third or fourth ports to the first or second ports, while having substantially no cumulative effect on the polarization of signals passing in the opposite direction;

14. A cross-connect apparatus comprising:

a first port;

a second port;

a third port;

a fourth port;

first routing means for directing first signals comprising wavelength channels from a first subset of optical frequencies from the first port to the third port, and from the fourth port to the second port; and

second routing means for directing signals comprising wavelength channels from a second set of optical frequencies, independent of the first subset of optical frequencies, from the second port to the third port, and from the fourth port to the first port.

15. The apparatus according to claim 14, wherein the first and second routing means comprise:

first polarization beam splitter means for dividing the first signals launched via the first port into orthogonally polarized sub-beams, and for combining orthogonally polarized sub-beams launched via the fourth port for output via the first port;

first polarization rotating means for ensuring both sub-beams exiting the first polarization beam splitter means have a first polarization, and for ensuring both sub-beams entering the first polarization beam splitter means have orthogonal polarizations;

second polarization beam splitter means for dividing the second signals launched via the second port into orthogonally polarized sub-beams, and for combining orthogonally polarized sub-beams launched via the fourth port for output via the second port;

second polarization rotating means for ensuring both sub-beams exiting the second polarization beam splitter means have the first polarization, and for ensuring both sub-beams entering the second polarization beam splitter means have orthogonal polarizations;

third polarization beam splitter means for combining orthogonally polarized sub-beams launched via the first or second ports for output via the third port;

third polarization rotating means for ensuring both sub-beams entering the third polarization beam splitter means have orthogonal polarizations;

fourth polarization beam splitter means for dividing signals launched via the fourth port into orthogonally polarized sub-beams;

fourth polarization rotating means for ensuring both sub-beams exiting the fourth polarization beam splitter means have the first polarization;

birefringent crystal interleaver means receiving the first and second signals from the first and second ports, respectively, for rotating the polarization of the first signals by 90°, while having no cumulative effect on the polarization of the second signals; and

polarization dependent beam directing means for directing sub-beams from the first and second ports to the third port, and for directing sub-beams from the fourth port to the first and second ports.

16. The apparatus according to claim 15, wherein the polarization dependent beam directing means comprises a walk-off crystal, which receives the first signals from the first port at a first level, the second signals from the second port at a second level, and the first and second signals from the fourth port at a third level;

rotating means for rotating the polarization of the first and second signals by 90° after a first pass through the walk-off crystal; and

reflecting means for directing the first and second signals back through the walk-off crystal and back through the birefringent crystal interleaver for a second pass;

whereby the first signal from the first port and the second signal from the second port are directed to the third port on the third level; and

whereby the first and second signals from the fourth port are directed to the second port on the second level and the first port on the first level, respectively.

17 The apparatus according to claim 15, wherein the birefringent crystal interleaver including a first birefringent element of length L, a second birefringent element of length 2L, and polarization rotators between the first and second birefringent elements.

18. The apparatus according to claim 16, wherein the birefringent crystal interleaver including a first birefringent element of length L, a second birefringent element of length 2L, and polarization rotators between the first and second birefringent elements.

19. The apparatus according to claim 14, further comprising an optical device coupled between the third port and the fourth port, wherein the optical device is selected from the group consisting of a channel equalizer, an optical amplifier, an erbium doped fiber amplifier, and an Add/Drop multiplexer.